Control Big Loads Easily With Tiny Mixed-Signal ICs

Dedicated thermal-switch/driver ICs and a handful of discrete parts simplify sensing and high-power load control.

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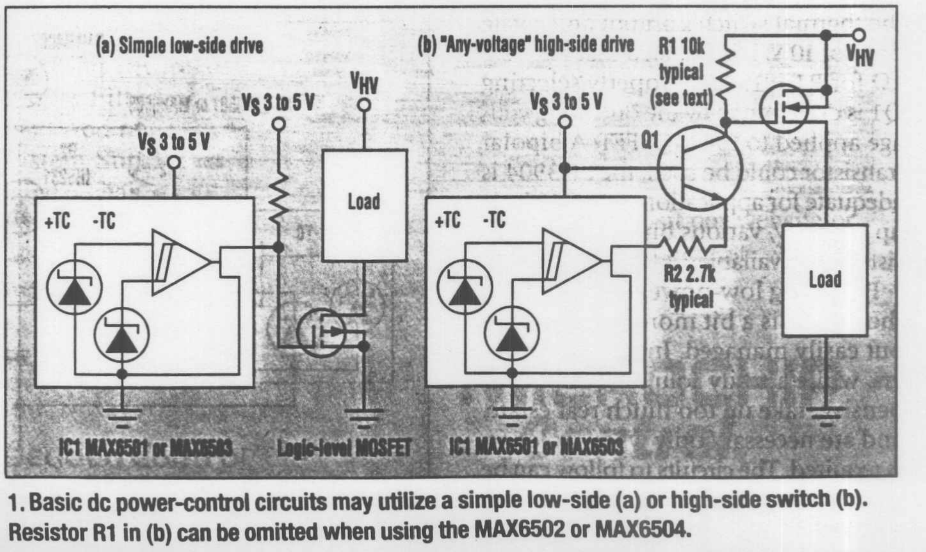
Discrete temperature-sensing and power-control functions often team up, but they're seldom seen together in a compact device. Temperature sensors take many forms, from simple bi-metallic switches and various types of transducers used through electronic interfaces to sophisticated digital-output silicon devices. These sensors generally require external conditioning electronics to control high-power loads.

A recent arrival in silicon sensors, the thermostat-output IC, travels part of the way toward an ultimate solution. But it still can't connect directly to high-power loads while keeping the overall circuit simple (i.e., implying a minimum of components). All-semiconductor solutions are coming along, however. A new mixed-signal chip, Maxim's 6501 series of thermal switches with logic-compatible outputs, stands as one example.

In low-power electronics systems, such as battery chargers or computer CPU monitors, a sensor and microcontroller are generally applied to maintain temperature. Depending on the situation, they activate fans or shut down the system when temperatures soar. The controller, however, is often underutilized as a thermal comparator. The dedicated thermal switch offers a simpler and more cost-effective solution for applications in which, for example, the temperature threshold is constant. Detecting the presence of ice would be one reason for such an application requirement.

Here, the 6501 series works well for functions like fan actuation *(Fig. 1a)*. Replace the fan with a heating element and the thermal switch with a MAX6504, and you have a heater that turns on at low temperatures. A high-side driver circuit *(Fig. 1b)*, while more complicated than its low-side counterpart, more easily handles grounded loads. These loads come into play when the load is remotely placed, as well as for fan circuits that have output signals for tachometers.

Silicon-based sensors also bring much higher accuracy than circuits based on bi-metallic switches, even for oven controllers and environmental-



1. Basic dc power-control circuits may utilize a simple low-side (a) or high-side switch (b). Resistor R1 in (b) can be omitted when using the MAX6502 or MAX6504.

or coolers that connect directly to high-power systems (120 or 240 V ac). With careful design, circuits based on silicon sensors and solid-state switches will be maintenance-free, precise, and cost-competitive with those based on bimetallic switches.

DC-Control Application

The simplest method of controlling a power device is to connect a MOSFET driver stage at the thermal switch's output *(Fig. 1a, again)*. This circuit can drive virtually any load up to the typical limits of the MOSFETs used in logic-level switching applications. High-side driving schemes aren't nearly as straightforward. The switch output may have to be coupled to a gate at a voltage much higher than the switch supply.

In Figure 1b, for example, a bipolar cascode stage must be connected to the switch's output in order to level shift the switch to a higher voltage. Selecting R1 makes a 10-V gate transition available to drive the power-switching MOSFET. For p-channel devices, which have a more narrow range of choices for logic-compatible gate swings, 10 V is required. For generic designs, set R2 to determine the current from the thermal switch output (not more than 3 mA for Maxim thermal switches). R1 is determined from the required gate swing at the MOSFET according to:

$$R2 = \frac{V_{GATE}}{\left(\dfrac{V_S - 0.6}{R1}\right)}$$

Using the circuit in Figure 1 and a 3.3-V supply, with 1 mA coming from the thermal switch's output and a gate drive of 10 V, it is revealed that R2 = 2.7 kΩ for R1 = 10 kΩ. Properly selecting Q1 is determined by the operating voltage applied to the MOSFET. A bipolar transistor could be used; the 2N3904 is adequate for applications up to 40 V. At up to 300 V, various bipolar npn transistors are available.

Powering low-power sensors from the ac line is a bit more complicated, but easily managed. Input transformers, while a ready solution, can be expensive, take up too much real estate, and are necessary only when isolation is required. The circuits to follow can be applied in a variety of temperature-monitoring tasks, from shutting down ways and water pumps when temperatures go below freezing. They require little to no maintenance. The major challenge is to drop down the ac line, which can be achieved with brute-force techniques, such as resistors, or more elegantly with capacitors.

Figures 2, 3, and 4 show methods of interfacing these low-power, low-voltage temperature switches to ac power-control circuitry. Using a relay as shown in Figure 1a is easy and could be applied to ac-control tasks. But efficiency drops when power levels rise because of increased relay dissipation. Figures 2 and 3 can control loads directly. Or, they can control contactors, which switch even more current. In Figure 2, power for the temperature switch is derived from a half-wave rectifier and a simple dropping resistor.

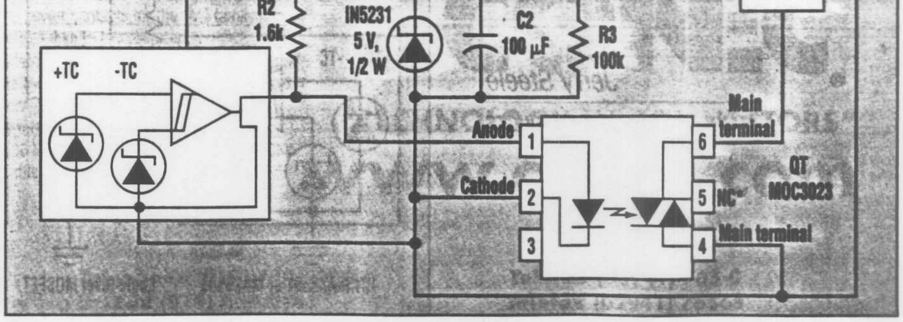
The only drawback is that the resistor, which is rated here at 2.5 W, will heat up. So the temperature switch should be located elsewhere. If heat or dissipation is a problem, capacitors can be used as voltage-dropping elements with virtually no power loss. In both circuits, the capacitors are installed in series with R1 and R3, which are normally connected directly (dashed lines). When capacitors are used, additional resistance is required at R1 to limit surge currents. Otherwise, so-called step functions on the ac line, like those caused by turning on the power switch in the middle of a cycle, will cause destructive currents.

ing of the rectifier when selecting the minimum value of the series resistance. In Figure 2, a far more conservative value for R1 was used than that actually required. That's because the nominal supply current is very low and the resistor's physical size is a factor. The designer only needs to determine the rated dissipation. The current flowing through R1 is 10 mA, where a 1/4-W, 2.7-kΩ resistor fits the bill. The peak current under these conditions is 220 × 1.4/R1 = 114 mA, which is well within the limits of any component appearing in the loop.

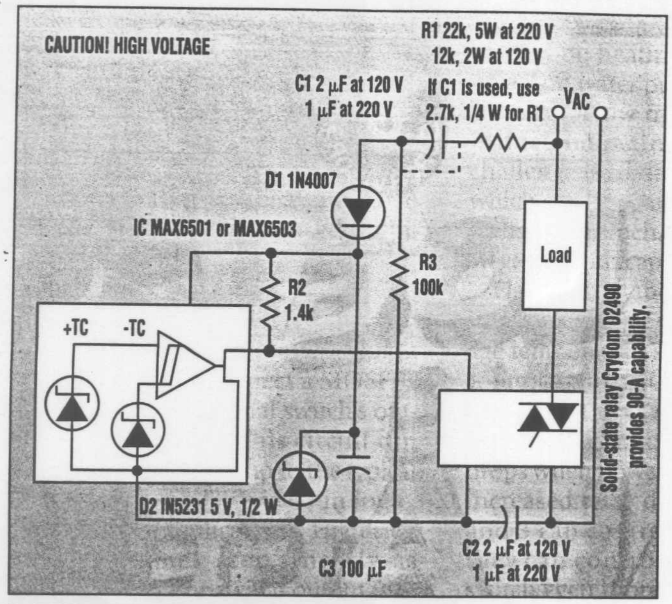
Zener Diode At Risk

The device most at risk during surge-current periods is probably the zener diode, although capacitor C1 will absorb most of the energy. The output of the temperature switch is coupled directly to the gate of the triac optocoupler. Select resistor R2 to provide the current required by the LED, in this case slightly more than 3 mA.

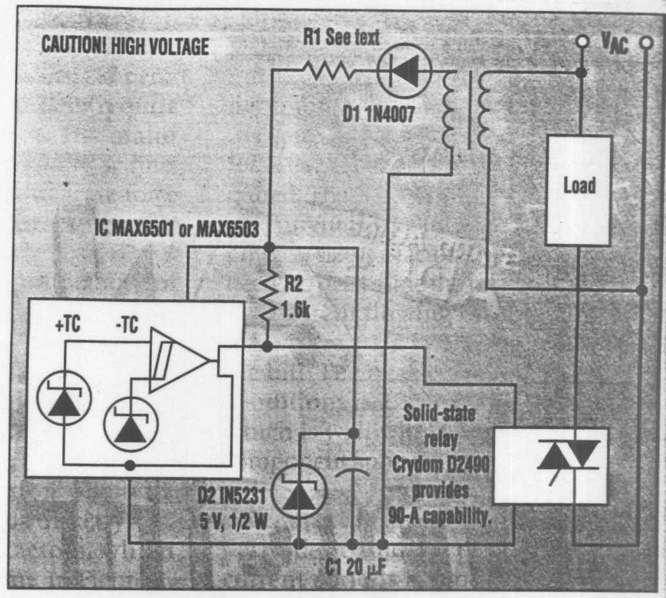
The circuit in Figure 3 functions identically to Figure 2, but provides signal isolation from the ac line by using a solid-state-relay (SSR) module. Again, capacitor coupling to the ac line is used. SSR modules, such as these from Crydom, require less than 3.4 mA. So they can connect directly to the output of the temperature switch. As in Figure 2, pullup resistor R2 must be appropriately sized. R2 is equal to 1.4 kΩ, assuming a 5-V supply. Capacitor coupling to the ac line provides some isolation, but



2. When ac loads are involved, controlling them is easily accomplished by switching to triac-output optocouplers. The circuit can control loads directly or through contactors.



3. In this ac switching circuit, capacitive isolation of the ac power line is used, along with an optocoupler/triac module.



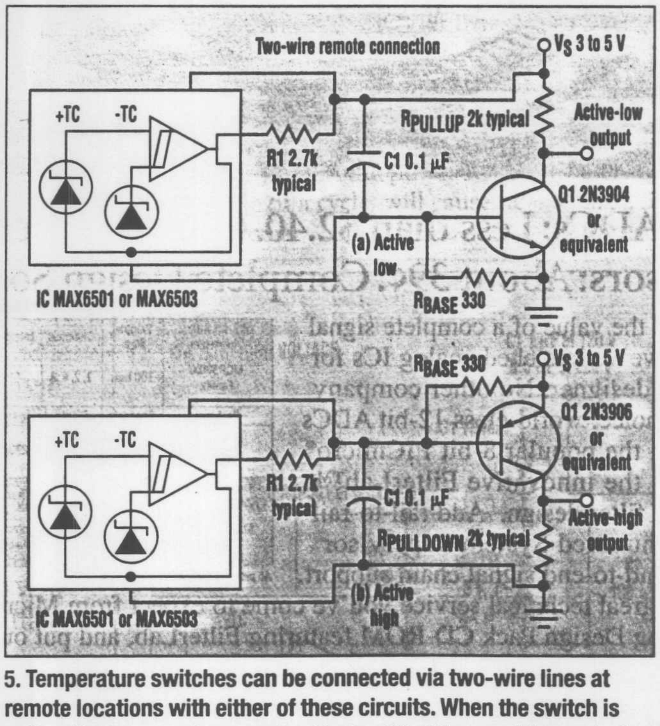
4. For applications in which human safety is an issue, transformer coupling provides true isolation of the ac power line.

its primary purpose is to drop the line voltage without generating heat.

In systems where true line isolation is required for human safety, a transformer becomes a necessity. The circuit in Figure 4 gives the temperature switch power from a transformer. That transformer needs to provide at least 8-V peak (5.6 V rms). This voltage, with the bias current flowing through zener D2 (assume 5 mA), determines the value of R1. If the transformer supplies less than 1 A, omit R1 to simplify the circuit. Note that the MAX6501-6504 works off a nominal 5-V supply voltage in these circuits. In actual operation, it can operate from 2.7 to 5.5 V.

In some systems, the temperature sensor and its load resistor R1 need to be remotely located from the power-control circuitry. Figure 5 shows two arrangements. The most common complaint in using these silicon sensors is that they appear to require three leads: power, ground, and output. These devices can be used over a two-wire connection, as well as in systems where the ground allows for even a single wire. The circuit in Figure 5a provides an active-low output, the traditional configuration. The active-high configuration in Figure 5b can be applied over a single wire if the entire sensing and power-control circuitry hold a common ground (less than 200-mV drop, dc or ac p-p, or combined).

In both circuits, the quiescent current is typically 85 µA. It's not sufficient to turn on output transistor Q1. When the sensor output becomes active, the load resistor R1 draws about 3 mA and Q1 turns on. Select R_{BASE} so that Q1 retains off when the sensor is inactive, yet pulls enough current to drive Q1 when the sensor turns on. A good rule of thumb is to select R_{BASE} to yield a drop of about 1 V.



5. Temperature switches can be connected via two-wire lines at remote locations with either of these circuits. When the switch is active, the increase in current activates Q1 at the receiving end of the line. The MAX6501 and MAX6503 have factory-preset trip points. The output of the MAX6501 goes low when the temperature rises above the set point, while the 6503 goes low when the temperature falls below it. Grounding the hysteresis-set pin on the MAX6501 through MAX6504 (not shown) provides 2-C hysteresis. Connecting the pin to V_S provides 10 C of hysteresis.

In practice, Q1's base will limit the actual drop to about 650 mV. Re-check to ensure that the drop is less than 300 mV when the circuit is operating during quiescent conditions. The value of Q1's collector load resistance is basically determined by the supply voltage and its collector current, which should be kept to a value under 30 mA.

Resistor R1's highest possible value is determined by circuit leakage currents, and seldom will be higher than 100 kΩ. To incorporate Figure 5a into the preceding power-control circuits, substitute the transistor for the temperature switches. Doing so with Figure 5b demands some modification to the logic circuitry.

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